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Odonata (Insecta) communities along an elevational gradient in the Atlantic forest of southeastern Brazil, with the description of the female of *Heteragrion mantiqueirae* Machado, 2006

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Abstract. Despite the important role of the order Odonata in ecosystems, there is a lack of information about dragonfly communities in several regions, high elevation sites, and environmentally protected areas in Minas Gerais State, Brazil. Our objective was to assess the abundance and richness of dragonfly and damselfly communities along an elevational gradient in the Atlantic Forest, southeastern Brazil. This study was conducted in the Fernão Dias Environmental Protection Area, Mantiqueira Mountain region, Gonçalves, Minas Gerais State, in sites covered by Seasonal Semideciduous and mixed forests. This is the first study of Odonata communities in the region. Samplings were carried out on 17 days from October 2019 to March 2020 at three elevation ranges (low, mid, and high). A total of 293 specimens, distributed in 39 species and 9 families, were sampled. Elevation did not influence the richness or abundance of dragonflies but altered community composition. Some species were found to be exclusive to high-elevation sites, such as *Heteragrion mantiqueirae* Machado, 2006, which was recorded for the first time in Minas Gerais and we provide a description and diagnosis of the single female collected in tandem. A novel species of the genus *Brechmorhoga* was found to occur at mid and high elevations. The composition of dragonfly communities depends on the degree of preservation and extension of forest areas. Therefore, conservation of forests in Gonçalves is crucial for preserving Odonata diversity in Minas Gerais State.

keywords: Anisoptera, altitude, diversity, dragonfly, preservation, Zygoptera

Introduction

The order Odonata comprises insects popularly known as dragonflies and damselflies (Machado et al., 1998) and is composed by two suborders, Anisoptera (Epiprocta) and Zygoptera (Corbet, 1999), of which 901 species, 147 genera, and 15 families occur in Brazil (Pinto, 2020). As nymphs, dragonflies and damselflies occupy lentic and lotic freshwater environments; some species occur mainly in

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forests with low anthropogenic disturbances (Machado, 1988; Ferreira-Peruquetti & De Marco, 2002; Souza et al., 2018) and can, therefore, be used as bioindicators of the environmental quality of forest ecosystems (Machado, 1988; Gonçalvez, 2012; Oliveira-Junior et al. 2015, 2019a). For the purposes of this study, individuals of Odonata will be referred to collectively as dragonflies.

Several inventory studies of dragonfly species have been conducted in Minas Gerais State, Brazil (Santos, 1966, 1970; Ferreira-Peruquetti & De Marco, 2002; Almeida et al., 2013; Souza et al., 2013; Bedê et al., 2015; Vilela et al., 2016; Dos Anjos 2017; Souza et al., 2017; Amorim et al., 2018; Borges et al., 2019; Barbosa et al., 2019; Vilela et al., 2020; Silva & Souza 2020), but many localities, ecosystems, and Conservation Units (UCs) of the State still lack information on community diversity of Odonata. Conservation Units are an important tool for biodiversity conservation, helping to preserve various species and environmental services (Siqueira et al., 2017; Steinke et al., 2018), which justifies inventory studies in UCs.

For instance, in a survey of Odonata currently under progress in the Itacolomi State Park, Ouro Preto, Minas Gerais, a new species of the genus *Heteragrion* was identified and *Cyanallagma trimaculatum* (Selys, 1876) was rediscovered after 147 years (Ávila Jr et al., 2020a; Ávila Jr et al., 2020b). The absence of biodiversity information impairs the effectiveness of management programs for biota conservation, even in the Atlantic Forest, which is generally well sampled compared with other Brazilian biomes.

The Atlantic Forest is heterogeneous biome and comprises a set of forest formations and associated ecosystems that differ in climate and elevation, including Dense, Mixed and Open Ombrophilous forests, Seasonal Deciduous and Semideciduous forests; restingas (coastal vegetation); mangrove swamp; high meadows; marsh; and Caatinga enclave moist forests (Oliveira Filho, 2006). Additionally, this biome is one of the richest and most threatened biodiversity hotspots of the planet, in which a variety of endemic and endangered faunal and floral species occur (Uehara-Prado et al., 2007; Maldonado-Coelho & Marini, 2004; Ruschel, et al., 2007). Unfortunately, habitat degradation and extinction of various organisms are common, making its preservation a priority (Mayers et al., 2000; Steinke et al., 2018).

Apart from the examples described above, several environmental factors influence insect diversity and distribution, such as water physicochemical characteristics, soil conditions, phytophysiognomies, elevation, resource availability, and abiotic variables (Freitas et al., 2007; Fernandes, 2016). Along elevational gradients, oscillation of temperature and relative humidity, low atmospheric oxygen levels, and high wind speed and UV incidence are limiting factors of insect colonization (Hodkinson, 2005), particularly when combined with reduced habitat area, primary production, and resource availability, which directly affect species richness, abundance, and community composition (Lawton et al., 1987; Henriques-Oliveira & Nessimian, 2010).

Elevation effects have been the focus of various studies on different insects in Brazil, such as butterflies (e.g., Carneiro et al., 2014; Henriques & Cornelissen, 2019) and social wasps (e.g., Albuquerque et al., 2015; Souza et al., 2015; Ribeiro et al., 2019), and some international studies have instigated elevation effects on the order Odonata (e.g., Samways, 1989; Leksono et al., 2017; Palacino-Rodríguez et al., 2020). In Brazil, however, only the studies carried out by Oliveira-Junior et al. (2015, 2019) and Oliveira-Junior and Juen (2019b) can be found on topic. It is known that altitude affects the composition of aquatic invertebrate communities (Tomanova et al., 2007), however the results found on the influence of elevation for Odonata are still divergent, especially in adulthood. According to Corbet (1999) and Oliveira-Junior et al. (2015), the elevation alone may not exert a great influence on dragonfly communities, especially in those species with great flight capacity of Anisoptera, but if associated with other environmental variables such as the area conservation degree or the physicochemical characteristics of the water, it could affect the composition and distribution of the Odonata fauna.

This study aimed to describe abundance and richness of dragonfly communities along different elevational gradients in the Atlantic Forest in southeastern Brazil and fill in gaps in knowledge concerning the distribution of Odonata in mountainous regions of the country. The elevational distribution pattern of adults of Odonata is still not well established, since most studies evaluate only the aquatic phases. Therefore, we tested the hypothesis that species richness decrease with increasing elevation, following the distribution pattern of species in mountains commonly described for other terrestrial insect groups (e.g. ants, dung beetles, butterflies, termites, galling herbivores etc; Fernandes, 2016 and references therein). Additionally, we provide the description and diagnosis of the hitherto unknown female of *Heteragrion mantiqueirae* Machado, 2006, collected during our expeditions. The

female belongs to Lencioni's *Heteragrion* Group A (Lencioni, 2013), which is composed of females possessing several rows of teeth on the ventral surface of genital valves.

Material and Methods

Study site

The study was conducted at the Fernão Dias Environmental Protection Area, located in Gonçalves (-22.503611, -45.5233333), southernmost part of Minas Gerais State, Brazil (Figure 1). The region is inserted in the Mantiqueira Mountain system and is covered by Seasonal Semideciduous and Mixed forest vegetation, the most common phytophysiognomies of the Atlantic Forest domain (Oliveira Filho, 2006). The climate is humid temperate (Köppen classification: Cwb), the annual average precipitation is about 1500 mm, average daily temperatures vary from 14 to 19 °C, and elevations range from 880 to 1670 m (a.s.l.) (Melo & Salino, 2007).

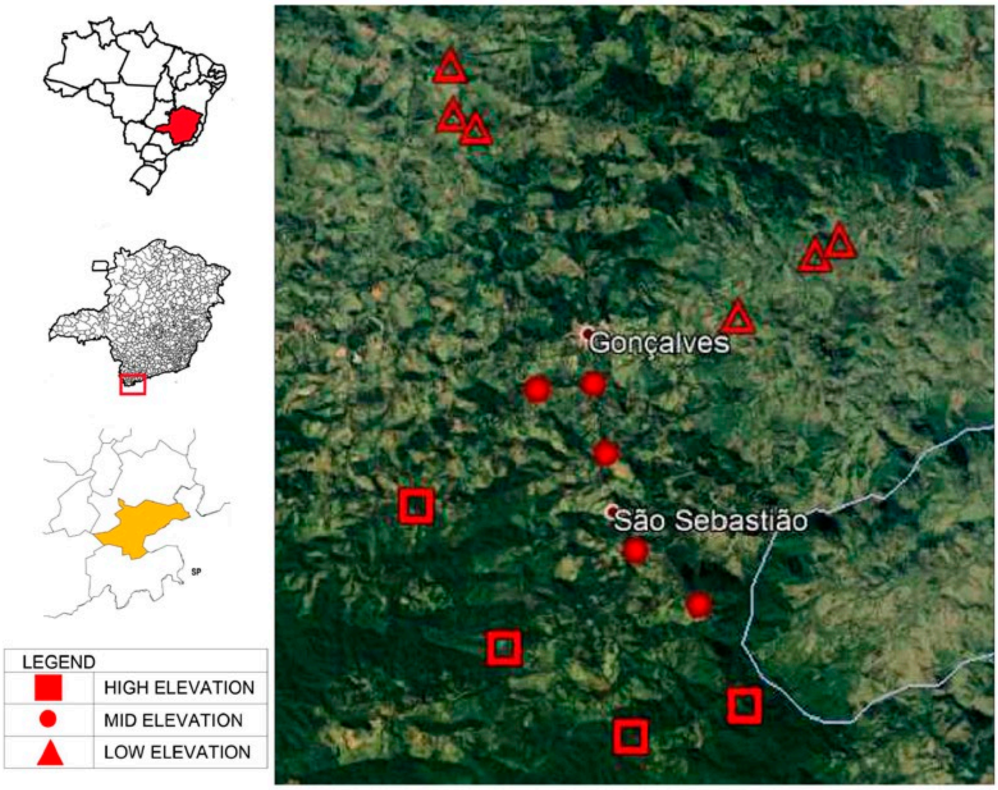

Figure 1. Map of the study area showing low-, mid-, and high-elevation sampling sites in Gonçalves, Minas Gerais State, Brazil.

Data sampling

Samplings were performed from October 2019 to March 2020 at low-, mid-, and high-elevation sites (880 to 1670 m a.s.l.) located at 160 m elevation intervals (Table 1 and Figure 1). Samples were performed on 17 days for 8 h a day, totaling 136 h of sampling effort equally distributed between elevation ranges. Adult dragonflies were captured using entomological nets in the morning and afternoon

from 9:00 to 17:00 h, according to Bedê et al. (2015) in lentic and lotic environments and associated terrestrial ecosystems. Sampled individuals were placed in entomological envelopes labeled with the date and place of collection. Subsequently, dragonflies were sacrificed by immersion in acetone P.A. and identified by specialists. For specimens identification we used the keys contained in Garrison et al. (2006, 2010) for genus level of Zygoptera and Anisoptera, Lencioni (2017) for specific identification of Zygoptera and additional literature for each genera and species when needed. Specimens were deposited in the Biological Collection of Social Wasps of the Federal Institute of Southern Minas Gerais (CBVS, IFSULDEMINAS), Inconfidentes Campus, Brazil.

Table 1. Ecological, economic, and social characteristics of Odonata sampling sites along an elevational gradient in the Fernão Dias Environmental Protection Area, southern Minas Gerais State, Brazil. Coordinates of the sampled locations at each elevation are shown below.

Characteristic	Low elevation	Mid elevation	High elevation
Elevation range	880 to 1090 m (a.s.l.)	1250 to 1410 m (a.s.l.)	1570 to 1670 m (a.s.l.)
Vegetation type	Semideciduous forest	Mixed and Semideciduous forest	Mixed forest
Fragmentation state	Highly fragmented	Moderately fragmented	Less fragmented
Succession stage	Initial or intermediate	Intermediate	Advanced
Canopy formation	Rare	Uncommon	Frequent
Pasture growth	High	Low	Low
Eucalyptus cultivation	Present	Present	Present
Ecotourism activities	Low	High	High
Lentic ecosystems	Present	Present	Present
River/stream width	2 to 10 m	2 to 5 m	<2 m
Riparian forest	<5 m	5 to 10 m	<10 m
Residential areas	Many	Many	Few
Lotic ecosystems	Present; greater water volume and current speed; width between 2 to 10 m	Present; greater water volume and current speed; width between 2 to 5 m	Present; greater water volume and current speed; width <2 m
Coordinates			
Locations	**Low elevation**	**Mid elevation**	**High elevation**
Area 1	22.7007 S / 45.8453 W	22.6739 S / 45.8528 W	22.7415 S / 45.8438 W
Area 2	22.6392 S / 45.7975 W	22.7105 S / 45.8327 W	22.7359 S / 45.8195 W
Area 3	22.6552 S / 45.8207 W	22.6699 S / 45.8537 W	22.7235 S / 45.8723 W
Area 4	22.6028 S / 45.8861 W	22.6694 S / 45.8486 W	22.7447 S / 45.8923 W
Area 5	22.6164 S / 45.8793 W		
Area 6	22.6422 S / 45.8030 W		

Data analysis

To assess the frequency of distribution of dragonfly species within the community as a whole, we classified singletons (one individual sampled) and doubletons (two individuals sampled) as rare. Diversity was measured by elevation range using the Shannon diversity index (H'), evenness by Pielou's index (J, calculated from H'), and dominance by the Simpson index (D). Differences between elevation ranges were analyzed by the Kruskal–Wallis test. Spatial variations in the distribution of sampled organisms were visually represented by nonparametric multidimensional scaling (nMDS). Abundance data were tested for homogeneity of multivariate dispersion (PERMDISP) (Anderson et al., 2006) between elevation ranges and subjected to nonparametric multivariate analysis of variance (PERMANOVA). Cluster analysis was performed based on a Jaccard similarity matrix constructed from presence/absence data. Dendrograms were constructed by unweighted pair group method with arithmetic mean (UPGMA), where the similarity between the groups is the average of similarities - the UPGMA links the smallest distances and recalculates new distances using arithmetic means for a new grouping, thus linking groups by the average similarity between their elements, increasing the ability to discriminate groups (Valentin, 2012), so we used this method because it best adjust for our data. All analyses were performed using PAST software version 3.24 (Hammer et al., 2001).

Taxonomy

The female description of *H. mantiqueirae* Machado, 2006 was based on a single specimen collected in tandem in a lotic environment of dense vegetation within a mixed forest (Figure 2). The collecting site is located at 1660 m (a.s.l.) (-22.7418361, -45.8459722).

Habitus was scanned with an Epson V600 Perfection at colored 1200 dpi with 200% magnification. Illustrations were made using trace paper and scanned with Epson V600 Perfection at black and white 1200 dpi with 100% magnification.

Morphological terminology follows Bota-Sierra & Novelo-Gutiérrez (2017); Lencioni (2017); Vilela et al. (2019). All measurements are in millimeters (mm).

Abbreviations in the text are used as follows: AL, abdomen length (including cercus); DP, dorsal plate of intersternite; FW, fore wing; HW, hind wing; Is, interternite; Pt, pterostigma; Px, postnodal crossvein; Se, setifer; S1–10, abdominal segments 1 to 10; TL, total length (including cercus).

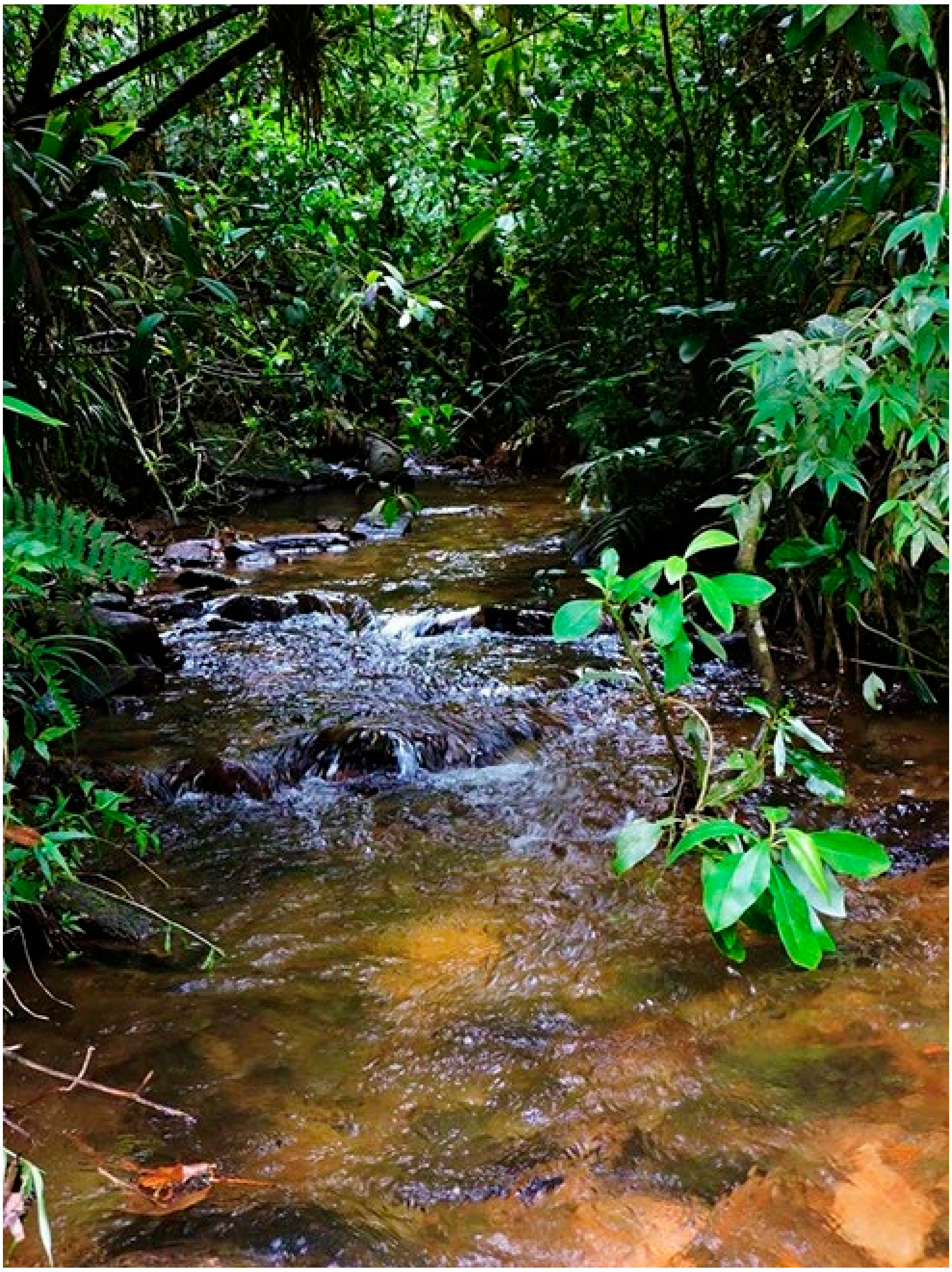

Figure 2. Place of collection of *Heteragrion mantiqueirae* Machado, 2006, at the APA Fernão Dias, Southern Minas Gerais State.

Results

Richness, abundance and distribution of Odonata communities

A total of 293 Odonata individuals were sampled, belonging to 39 species distributed throughout nine families (three families from suborder Anisoptera and six families from suborder Zygoptera), including two new records to Minas Gerais State: *Hetaerina brightwelli* (Kirby, 1823), and *Heteragrion mantiqueirae* Machado, 2006 (Table 2, Figure 4). Libellulidae was the family with the highest species

richness (16 species, 41% of the total richness), followed by Coenagrionidae (eight species, 20.51%), Calopterygidae (four species, 10.25%), Heteragrionidae (three species, 7.69%), Protoneuridae (two species, 5.12%), and Aeshnidae, Gomphidae, Lestidae, and Megapodagrionidae (one species each, 2.56%). Libellulidae was also the most abundant family (*n* = 75 individuals, 25.6% of the total abundance), followed by Calopterygidae (*n* = 77, 26.27%), Coenagrionidae (*n* = 70, 23.9%), Heteragrionidae (*n* = 42, 14.33%), Gomphidae and Megapodagrionidae (*n* = 7 each, 2.38%), Protoneuridae (*n* = 6, 2.04%), Aeshnidae (*n* = 5, 1.7%), and Lestidae (*n* = 4, 1.36%). The most abundant species were *Hetaerina longipes* Hagen in Selys, 1853 (Zygoptera: Calopterygidae, *n* = 59), *Heteragrion rogertaylori* Lencioni, 2013 (Zygoptera: Heteragrionidae, *n* = 32), *Oxyagrion terminale* Selys, 1876 (Figure 4a) (Zygoptera: Coenagrionidae, *n* = 31), and *Erythrodiplax fusca* (Rambur, 1842) (Anisoptera: Libellulidae, *n* = 17). Altogether, these four species accounted for 47.44% of sampled individuals.

Table 2. Richness, abundance, dominance, Shannon-Wiener diversity index, Pielou's evenness, Chao-1 species estimator, and number of exclusive species of Odonata sampled (*N* = 293) by elevation range in the Fernão Dias Environmental Protection Area, southern Minas Gerais, Brazil. *New records to Minas Gerais State.

Suborder/family/species		Elevation		
		Low	Mid	High
Anisoptera				
Aeshnidae				
	Coryphaeschna sp. 1	0	0	1
	Rhionaeschna planaltica (Calvert, 1952)	0	0	1
	Rhionaeschna punctata (Martin, 1908)	0	0	3
Gomphidae				
	Progomphus gracilis Hagen in Selys, 1854	0	0	7
Libellulidae				
	Brechmorhoga sp. nov.	0	3	2
	Dasythemis mincki (Karsch, 1889)	0	3	3
	Erythrodiplax sp.	0	0	2
	Erythrodiplax aff. *avittata* Borror, 1942	2	3	0
	Erythrodiplax aff. *basalis* (Kirby, 1897)	0	2	2
	Erythrodiplax castanea (Burmeister, 1839)	0	0	1
	Erythrodiplax fusca (Rambur, 1842)	11	5	1
	Erythrodiplax media Borror, 1942	0	0	1
	Macrothemis imitans Karsch, 1890	5	1	2
	Macrothemis marmorata Hagen, 1868	1	0	3
	Macrothemis tenuis Hagen, 1868	0	8	2
	Micrathyria didyma (Selys, 1857)	1	0	0
	Micrathyria stawiarskii Santos, 1953	1	0	3
	Perithemis lais (Perty, 1834)	1	1	0
	Perithemis mooma Kirby, 1889	2	0	0
	Orthemis discolor (Burmeister, 1839)	3	0	0

Suborder/family/species		**Elevation**		
		Low	**Mid**	**High**
Zygoptera				
Calopterygidae				
	Bryoplathanon globifer (Hagen in Selys, 1853)	0	0	6
	*Hetaerina brightwelli** (Kirby, 1823)	0	3	0
	Hetaerina longipes Hagen in Selys, 1853	19	32	8
	Hetaerina rosea Selys, 1853	9	0	0
Coenagrionidae				
	Argia sordida Hagen in Selys 1865	6	2	9
	Argia modesta Selys, 1865	1	0	4
	Acanthagrion gracile (Rambur, 1842)	8	2	0
	Acanthagrion cf. *lancea* (Selys, 1876)	1	0	0
	Oxyagrion evanescens Calvert, 1909	0	1	0
	Oxyagrion mirnae Machado, 2010	0	0	3
	Oxyagrion terminale Selys, 1876	3	12	16
	Telebasis erythrina (Selys, 1876)	0	2	0
Heteragrionidae				
	Heteragrion aurantiacum Selys, 1862	1	2	0
	Heteragrion mantiqueirae Machado, 2006*	0	0	7
	Heteragrion rogertaylori Lencioni, 2013	1	17	14
Lestidae				
	Archilestes exoletus (Hagen in Selys, 1862)	1	3	0
Megapodagrionidae				
	Allopodagrion contortum (Hagen in Selys, 1862)	2	3	2
Protoneuridae				
	Forcepsioneura itatiaiae (Santos, 1970)	0	0	4
	Peristicta forceps Hagen in Selys, 1860	1	0	1
Ecological parameters	Richness	21	19	26
	Abundance	80	105	108
	Dominance	0.1137	0.1472	0.07184
	Diversity	2.529	2.366	2.908
	Evenness	0.8305	0.8034	0.8926
	Chao-1 estimator	32.25	19.5	28.14
	Number of exclusive species	5	3	11

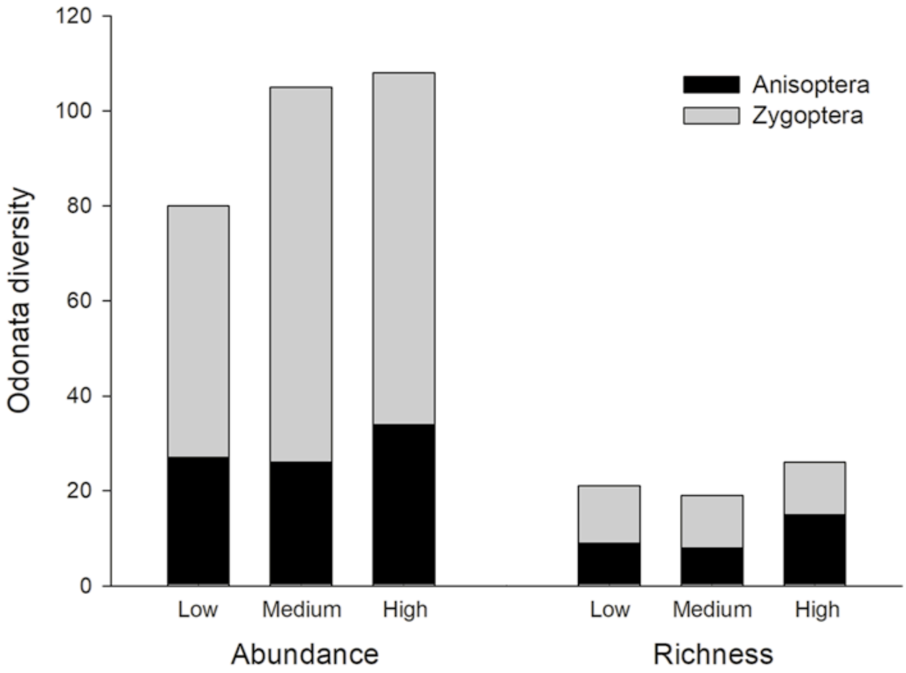

Figure 3. Richness and abundance of Odonata communities, stratified by suborder, at low, mid, and high elevations in the Fernão Dias Environmental Protection Area, southern Minas Gerais State, Brazil.

High-elevation sites had the highest richness (n = 26), abundance (n = 108), number of exclusive species (n = 11), and diversity (H' = 2.908) (Table 2 and Figure 3). Six species were singletons and five were doubletons, indicating that 28.2% of the dragonfly species collected were rare. Five species were exclusive to the low-elevation range (*Acanthagrion cf. lancea* Selys, 1876, *Hetaerina rosea* Selys, 1835, *Micrathyria didyma* (Selys in Sagra, 1857) (Figure 4b), *Orthemis discolor* Burmeister, 1839, and *Perithemis mooma* (Kirby, 1889), three species to mid elevation *Hetaerina brightwelli* (Kirby, 1823), *Oxyagrion evanescens* Calvert, 1909, and *Telebasis erythrina* (Selys, 1876), and 11 to high elevation (Table 2).

Elevation effect on Odonata diversity and species description

No distinct groups were formed by nMDS of species abundance. A stress value of 0.22 was observed, indicating adequate ordination (Kruskal & Wish, 1978). Odonata abundance did not differ between elevation ranges, as assessed by both PERMDISP (F = 0.503, P > 0.05) and PERMANOVA (F = 0.612, P > 0.05). The Jaccard index revealed dissimilarity between samples taken at different elevation ranges (Figure 5). Two clusters were formed, one comprising low and mid elevations (0.43) and the other comprising low + medium and high elevation ranges (0.32). No differences in diversity were observed between elevation ranges (P > 0.05). Although diversity was numerically higher at high-elevation sites, species dominance was lower (D = 0.0718) and evenness was higher (J = 0.8926) at this range.

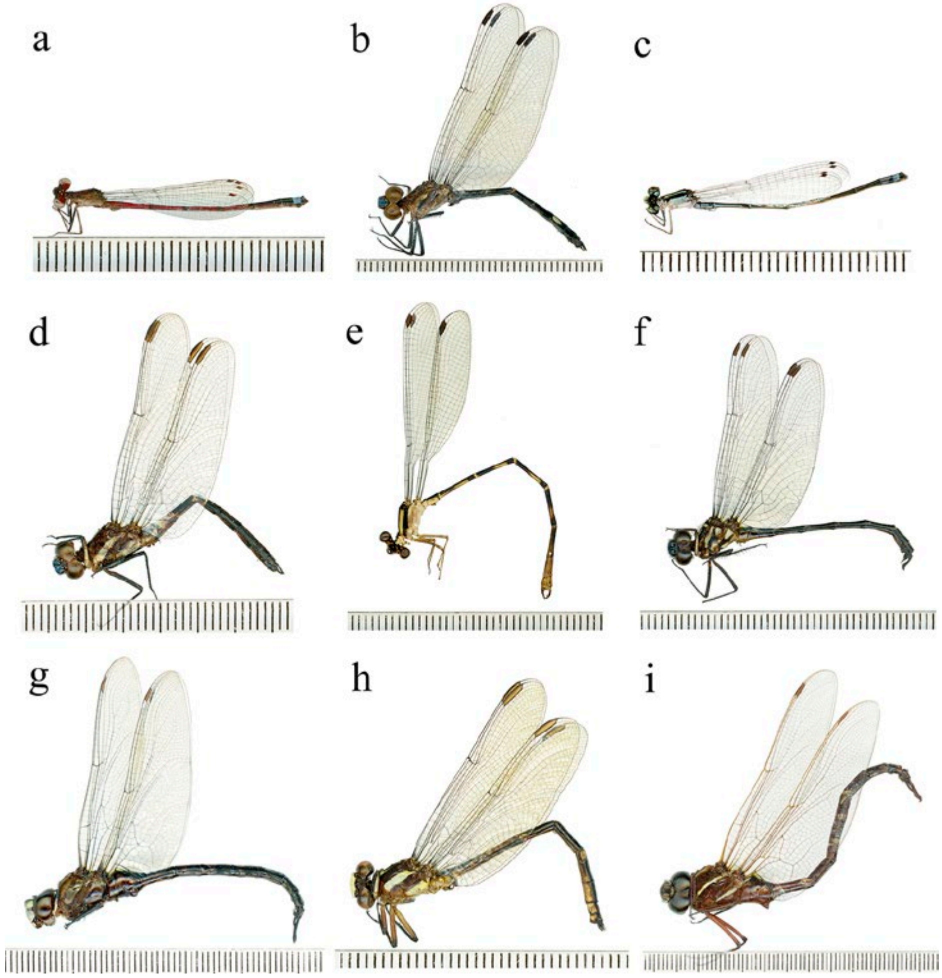

Figure 4. Some species reported in this study: (a) *Oxyagrion terminale* Selys, 1876; (b) *Micrathyria dydima* (Selys in Sagra, 1857); (c) *Acanthagrion gracile* (Rambur, 1842); (d) *Dasythemis mincki* (Karsch, 1890); (e) *Heteragrion mantiqueirae* Machado, 2006; (f) *Macrothemis marmorata* Hagen, 1868; (g) *Rhionaeschna planaltica* (Calvert, 1952); (h) *Progomphus gracilis* Hagen in Selys, 1854; (i) *Rhionaeschna punctata* (Martin, 1908).

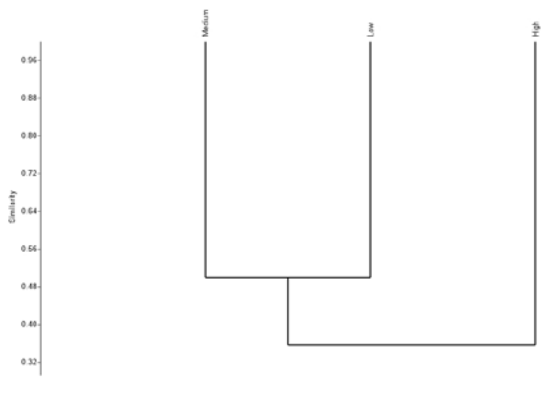

Figure 5. Jaccard similarity among Odonata communities along an elevational gradient in the Fernão Dias Environmental Protection Area, southern Minas Gerais State, Brazil.

The female of *Heteragrion mantiqueirae* Machado, 2006 (Figures 6a–h)

Material studied

1♀ (in tandem). BRAZIL, Minas Gerais, Gonçalves, APA Fernão Dias (22.6708 S, 45.8669 W, 1410 m asl), 12.x.2019, M.M. Souza leg.

Head (Figures 6a, b) − Labrum pale with light brown stripe surrounding the distal extremity to the middle, postclypeus black with the edge pale, postfrons black with a black spot below each antenna, antenna black, black band connecting middle of the eyes to occiput, vertex black, occipital bar and occipital ridge black.

Thorax (Figures 6b, c, e) – Prothorax: anterior lobe pale with black spot in the center; middle lobe pale with light oval black spot on each side, and black strip in the center; hind lobe with rounded margins, pale laterally with broad black spot in the middle; propleuron pale. Pterothorax: middorsal carina black; humeral black stripe accompanying the middorsal carina; mesepisternum pale with light brown stripe; mesinfraepisternum with brown spot; mesepimeron with black stripe below the mesopleural suture becoming lighter near the mesinfraepisternum; metepisternum and metepimeron pale, black spot near the metapleural fossa; antealar crest and antealar carina black; interesternite rounded, kidney-like, broader than and surpassing setifer, presence of a dorsal plate extending up close to the first thoracic spiracle (Figure 6d).

Wings (Figure 6b) − hyaline with dark brown venation; pterostigma brown, proximal side oblique, overlying two cells in FW and three cells in HW; two post-quadrangular cells; 19 Px in FW and 17 in HW.

Abdomen (Figures 6b, f–h) − S1 pale with a dorsal black spot; S2−9 connected by pale basal rings, black dorsally, becoming dark/light brown towards the venter; S10 light brown; genital valves of ovipositor at the same level of S10, its ventral edge containing several rows of teeth; cerci brown, conical, slightly surpassing S10 length.

Measurements [mm] – TL 47.2; AL 37.8; FW 32.2; HW 31.2; Pt 2.3.

Differential diagnosis

The female of *H. mantiqueirae* can be separated from its female congeners by the following combination of characters (considering here only *Heteragrion itacolomii* Ávila Jr, Lencioni & Carneiro, 2020, a Group A species with described female intersternite): hind lobe with rounded margins, pale laterally with a broad black spot in the middle (in *H. itacolomii* rounded margins, pale laterally with small black spots on the edges, broad spot in the middle); intersternite rounded, kidney-like, broader than and surpassing setifer (in *H. itacolomii* not kidney-like, dorsally curved with dorsal end elongated and rounded); presence of a cylindrical dorsal plate extending up close to the first thoracic spiracle (in *H. itacolomii* dorsal plate absent); ovipositor at the same level of S10 (in *H. itacolomii* slightly surpassing S10 level).

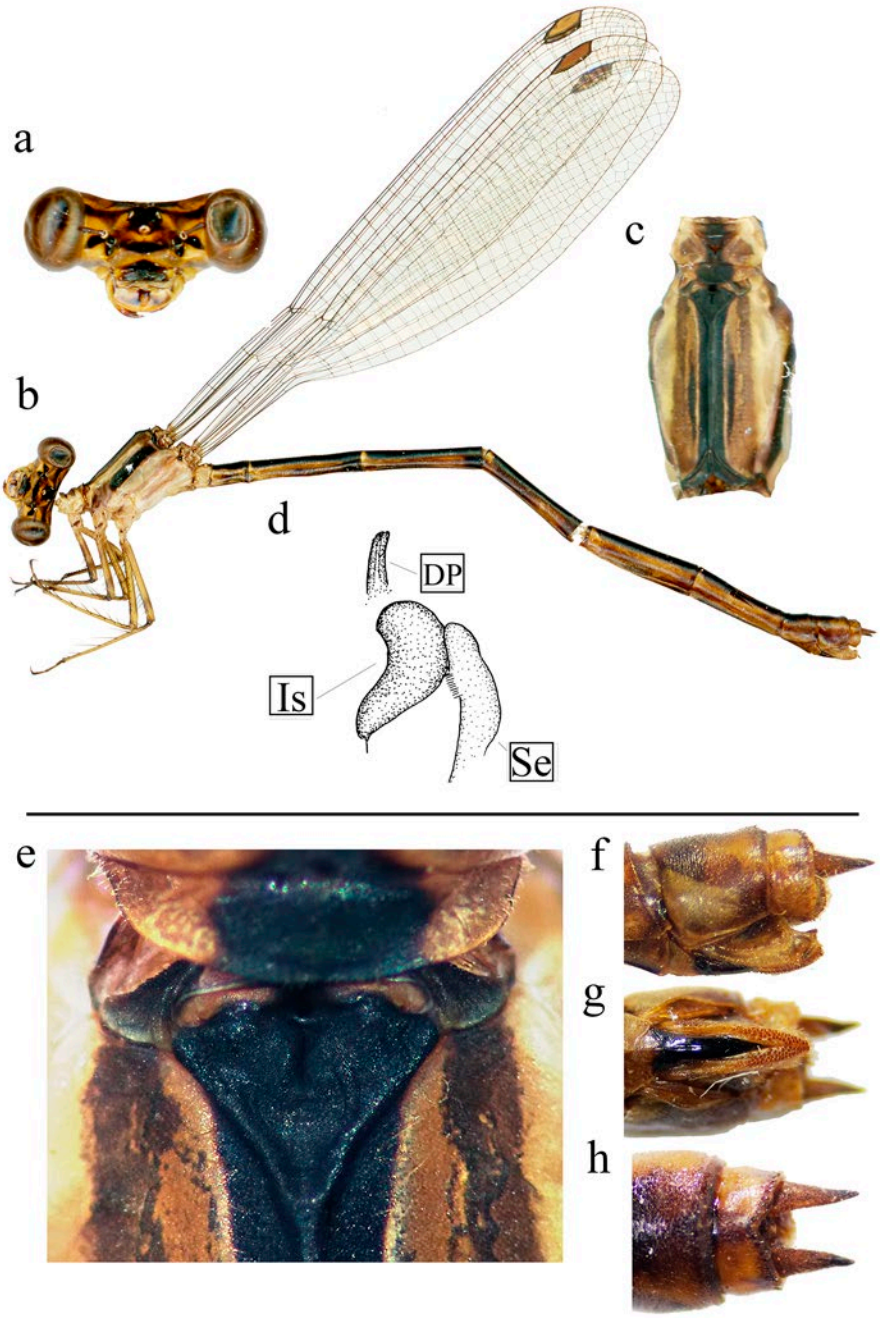

Figure 6. Female of *Heteragrion mantiqueirae*: (a) dorsal view of head; (b) lateral view of female habitus; (c) dorsal view of thorax; (d) intersternite; (e) dorsal view of mesostigmal plates and prothoracic hind lobe; (f) S9-S10, cerci and genital valves in lateral view; (g) genital valves in ventral view; (h) S9-10 and cerci in dorsal view. DP: dorsal plate; Is: intersternite; Se: setifer.

Discussion

Richness, abundance and distribution of Odonata communities

The two families with the highest species richness in this study, Libellulidae and Coenagrionidae, followed the pattern also observed in other inventories (Costa et al., 2000; Ferreira-Peruquetii & De Marco, 2002; De Marco & Viana 2005; Costa & Oldrini, 2005; Dalzochio et al., 2011; Souza et al., 2013; Bedê et al., 2015; Amorim et al., 2018; Borges et al., 2019; Barbosa, et al., 2019; Silva & Souza, 2020; Palacino-Rodrígues et al. (2020). This result was expected given the large number of Libellulidae and Coenagrionidae species occurring in Brazil, 237 and 325 respectively (Pinto, 2020), as they represent more than 60% of the total of Brazilian species.

Hetaerina species are abundant in lotic environments with faster currents (Vega-Sánchez et al., 2011; Amorim et al., 2018), *H. longipes* has been observed in different elevation ranges and biomes in Minas Gerais (Dos Anjos, 2017; Borges et al., 2019; Vilela et al., 2020). In this study, *Hetaerina* were found to be common at low and mid-elevation sites with the same environment (Table 1). *Hetaerina rosea* is widely distributed throughout the State, occurring mainly in lotic environments, including impacted areas (Peruquetti & De Marco, 2002; Souza et al., 2013; Bedê et al., 2015; Amorim et al., 2018; Silva & Souza, 2020). Here *H. rosea* was registered at low-elevation with high pasture growth, presence of Eucalyptus cultivation and initial or intermediate stages of ecological succession. We registered for the first time *H. brightwellii* in Minas Gerais occurring at mid-elevation and was previously reported to occur in Ombrophilous forests and Atlantic Forest sites in Rio de Janeiro State (Santos, 1997), Espírito Santo State (Storari et al., 2019) and São Paulo State (Costa et al., 2000). The high abundance of *Hetaerina* individuals may also be due to the morphological, physiological, and functional traits that contribute to their long life span (Córdoba-Aguilar & Cordero-Rivera, 2005; Pedraza-Hernández, 2010). Such factors may explain the distribution of *Hetaerina* species along the elevational gradient.

Oxyagrion terminale Selys, 1876 (Figure 4a) is widely distributed in Minas Gerais, occurring in Seasonal Semideciduous forest at 900–1100 m elevation (Souza et al., 2013), in Campos Rupestres (Rupestrian Fields) associated with Seasonal Semideciduous forests at 1000–1400 m elevation (Bedê et al., 2015), and in the Cerrado (Vilela et al., 2020), what explains its occurrence and frequency in the present study. *Oxyagrion evanescens* Calvert, 1909, found at mid-elevation sites, was reported to occur in Semideciduous forest areas in Minas Gerais (Souza et al., 2013; Amorim et al., 2018),

Heteragrion rogertaylori was recorded in dense, well-preserved areas of seasonal Semideciduous forests by Amorim et al. (2018). The same pattern was found herein, with the species being more abundant at mid and high-elevations (Figure 3) in lotic environments with dense vegetation cover. Environments with these characteristics are commonly inhabited by the family Heteragrionidae.

Erythrodiplax fusca (Rambur, 1842) also has wide geographical distribution across lotic and lentic environments (Ferreira-Peruquetti & De Marco, 2002), including fish tanks (Fonseca et al., 2004). *E. fusca* is used as an indicator of environmental impacts on watercourses and riparian forests (Monteiro Júnior et al., 2013), explaining the abundance of this species at low-elevation in our study in an environment with the presence of Eucalyptus cultivation, high degree of Pasture growth, and initial and intermediate stages of ecological succession.

The species *Acanthagrion* cf. *lancea* Selys, 1876 has one of the narrowest distributions among species exclusive to low-elevation ranges. Few studies have described its occurrence, although it has been observed in different ecosystems (Santos & Machado, 1983; Vilela et al., 2016; Barbosa et al., 2019; Borges et al., 2019), including artificial environments such as fish tanks (Vale & Souza, 2019).

On the other hand, *Telebasis erythrina* (Selys, 1876) was found to occur in Cerrado and Semideciduous forest regions in the State (Lencioni, 2011, 2017). *T. erythrina* (Selys, 1876) was found in regions of Cerrado and semideciduous forest in the State (Lencioni, 2011, 2017). Here, the species *T. erythrina* was recorded at mid-elevation, an environment with vegetation characterized by Mixed and Semideciduous forest with intermediate stages of ecological succession and low pasture growth, although it presents Eucalyptus cultivation and high ecotourism activities.

Orthemis discolor, *M. didyma* and *P. mooma* were exclusive to low-elevation and this same distribution pattern is also reported in other studies (De Marco & Resende, 2002; Peruquetti & De Marco, 2002; Giacomini & De Marco 2008; Souza et al ., 2013; Bedê et al., 2015; Vilela et al., 2016, 2020; Amorim et al. 2018; Barbosa et al., 2019; Borges et al., 2019; Silva et al., 2020; Souza et al., 2013; Souza et al., 2017).

The high elevation range was characterized by high canopy coverage. Previous studies identified three species occurring exclusively at this range in forest areas: *Bryoplathanon globifer* (Hagen in Selys, 1853) which was recorded above 1600 m in a mixed forest in Serra do Papagaio State Park (Dos Anjos, 2017), *Oxyagrion mirnae* Machado, 2010 and *H. mantiqueirae* Machado, 2006 (Figure 4e) above 1500 m in Zona da Mata Region (Machado, 2006, 2010)

A new species of the genus *Brechmorhoga*, which had been mistakenly identified as *B. tepeaca* by Santos (1946), was observed at high elevations. Kompier (2015) suggested that specimens of this species, treated by him as *B. tepeaca* sensu Santos, should be properly described. The results show that these species are restricted to the highest and most conserved areas and underscore the importance of preserving these locations in the municipality of Gonçalves.

Elevation effect on Odonata diversity

No distribution pattern was found for Odonata along the elevational gradient of Fernão Dias Environmental Protection Area. Probably other factors than altitude have a greater influence on the dragonfly communities in this area. Different biotic and abiotic factors, such as vegetation cover, resource availability, temperature, and relative humidity, are directly influenced by elevation (Fernandes, 2016) and, therefore, analysis of altitude alone may not provide sufficient insight into the effects of elevational gradient on diversity (Körner, 2007). We work here with categorical variables (low, mid and high elevation) and did not find a statistically significant distribution pattern. However, if the data were categorical the results could be different and there could be a tendency for dragonfly distribution along the elevational gradient. In this study, dragonfly distribution and composition along the elevational gradient seemed to be influenced by vegetation cover, fragmentation, and degree of conservation (Table 1). Such relationships were observed for Heteragrionidae, which were more abundant in freshwater environments with dense vegetation, slow currents, and high conservation degree (Machado, 1988; Ferreira-Peruquetti & De Marco, 2002), as also present in different locations and ecosystems in Minas Gerais, particularly in semideciduous forests (Souza et al., 2013; Machado & Souza, 2014; Machado, 2014 Amorim et al., 2018; Souza et al., 2018).

The Jaccard index revealed that the greater distance between high-elevation samples and other groups may indicate that this area has a diverse community. According to Kent and Coker (1992), values above 0.5 indicate high similarity, which did not occur in the present study. The Jaccard index measures similarity in a qualitative manner. That is, it analyzes the proportion of species shared between samples in relation to the total number of species and does not consider the number of individuals in a given sample; rather, it takes into account their presence or absence (Ferreira et al., 2008). This helps to explain the occurrence of exclusive species at the evaluated sites. Different communities were observed at different elevation ranges, particularly at high elevation (Table 2), in agreement with Leksono et al. (2017). Thus, elevation, degree of conservation, and forest size may affect Odonata community composition.

Leksono et al. (2017) investigated Odonata communities occurring at different elevation ranges in Java Island, Indonesia, and found no differences in absolute values of species richness between 15 and 1970 m (a.s.l.). However, a positive relationship was observed between elevation and general abundance, with the highest abundance at the highest elevation and the lowest abundance at the lowest elevation. In contrast, negative relationships between Odonata species richness and elevation were observed along a ~4000 m gradient in Ecuador (Jacobsen, 2004), a ~2500 m gradient in Switzerland (Oertli et al., 2002), and a ~1120 m gradient in Mexico (Novelo-Gutierrez & Gómez-Anaya, 2009). In Brazil, Oliveira-Junior et al. 2015, 2019) and Oliveira-Junior and Juen (2019b) investigated the occurrence of Odonata in Amazonian streams at 31–156 m (a.s.l.) elevation. The authors showed

that elevational gradient alone did not influence community composition but, when associated with degree of conservation and vegetation cover, significant effects on community composition were exerted.

Conclusions

Elevational gradient did not influence the richness or abundance of Odonata in the Fernão Dias Environmental Protection Area, Gonçalves, Minas Gerais, Brazil. However, differences in community composition were observed along the gradient, particularly at the high elevations, where many rare species were seen. For instance, we record, for the first time in Minas Gerais State, *H. mantiqueirae* Machado, 2006, and we present a description and diagnosis of a single female found at high elevation sites. Additionally, a new species of *Brechmorhoga*, found at mid-and high-elevation ranges is being currently described by some of the authors. The findings show that, at high elevation, a high degree of conservation resulted in a greater number of unique species, underscoring the relevance of forest preservation in the higher areas of this environmental protection unit. Forest restoration efforts should be directed toward mid- and, particularly, low-elevation sites.

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